GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: March 25, 1969

Project Title: Fernbank Science Center Seismic Noise Study

Project No.: A-1152

Project Director: Dr. L. T. Long

Sponsor: State Highway Department of Georgia

Effective . . . . March 10, 1969 . . . . Estimated to run until: . . . May 9, 1969 . . . .

Type Agreement: Letter Contract dated March 10, 1969 . . . . . . Amount: $ 1,000 . . . .

Reports: Final - At conclusion of project.

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PROJECT TERMINATION

Date July 1, 1969

PROJECT TITLE: Fernbank Science Center Seismic Noise Study

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PROJECT DIRECTOR: Dr. L. T. Long

SPONSOR: State Highway Department of Georgia

TERMINATION EFFECTIVE: May 9, 1969

CHARGES SHOULD CLEAR ACCOUNTING BY: June 30, 1969

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FINAL REPORT

PROJECT NO. A-1152

FERNBANK SCIENCE CENTER NOISE STUDY

BY

DR. LELAND TIMOTHY LONG
ASSISTANT PROFESSOR OF GEOPHYSICS

Performed for
STATE HIGHWAY DEPARTMENT OF GEORGIA
ATLANTA, GEORGIA

COVERING THE PERIOD
MARCH 1969 to MAY 1969
ISSUED MAY 20, 1969

1969

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

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FERNBANK SCIENCE CENTER NOISE STUDY

INTRODUCTION

The Fernbank Science Center (Dekalb County) presently operates a telescope in an area of presumed low seismic noise. The telescope is mounted on a cement pier which is set in bed rock and isolated from the building proper. The effect of the mounting is to stabilize the telescope and minimize its vibration. Vibration of the telescope can deteriorate its image and reduce its resolution and usefulness. Current sources of vibration are work activities and machines like air-conditioners in the building proper and seismic surface noise from traffic and industry nearby. At present, image deterioration is apparently not a problem related to seismic noise. However, the proposed Stone Mountain Freeway in passing about one thousand feet from the telescope is expected to increase the level of seismic noise. The object of project A-1152 is to estimate the expected increase in seismic noise and determine whether the higher level of seismic noise will cause image deterioration.

The method used involved two steps. First, current seismic noise levels in urban, suburban, and rural environments near major highways were measured to determine the expected maximum noise level as a function of distance from the major interchange. Second, photographs were taken during periods of quiet and simulated high level seismic noise to determine the relation between the seismic noise level and degree of image deterioration. The potential effect of the proposed freeway was finally estimated by comparison of the data from the two steps above.

INSTRUMENTATION

The instruments used to measure the seismic ground noise consisted of horizontal and vertical HS-10-1 geophones, Tektronix type 2A61 differential amplifiers, Lowpass filters, and a Texas Instrument two-channel "Oscillo/Riter" recorder. These were assembled as shown in Figure 1.

The HS-10-1 geophones have a natural frequency of one cps and were operated at 70% of critical damping. Their voltage sensitivities at critical damping, given in Table I, are flat above 1.5 cps.

TABLE I

Vertical Geophone	Volts/cm/sec.
88091	0.835
88092	0.905

Horizontal Geophone	Volts/cm/sec.
16599	0.897
16600	0.860

The Tektronix type 2A61 differential amplifiers were calibrated for a gain of 200 ± 10% at the 20 mv/div setting. A maximum gain of 4×10^5 was possible on the 0.01 mv/div setting. A 60 cps Line Notch Filter was superimposed on a 60 cps high-frequency attenuator and a .06 to .1 cps low-frequency attenuator. The resulting particle velocity response was flat from 0.2 to 9 cps.

Two optional low-pass filters were built as shown in Figure 1. Filter #1 ($R = 10\ k\Omega$, $C = 1.0\ \mu f$) has a 6 db cut-off at about 10 cps. Filter #2 ($R = 34.4\ k\Omega$, $C = 1.0\ \mu f$) has a 6 db cut-off at about 2 cps.

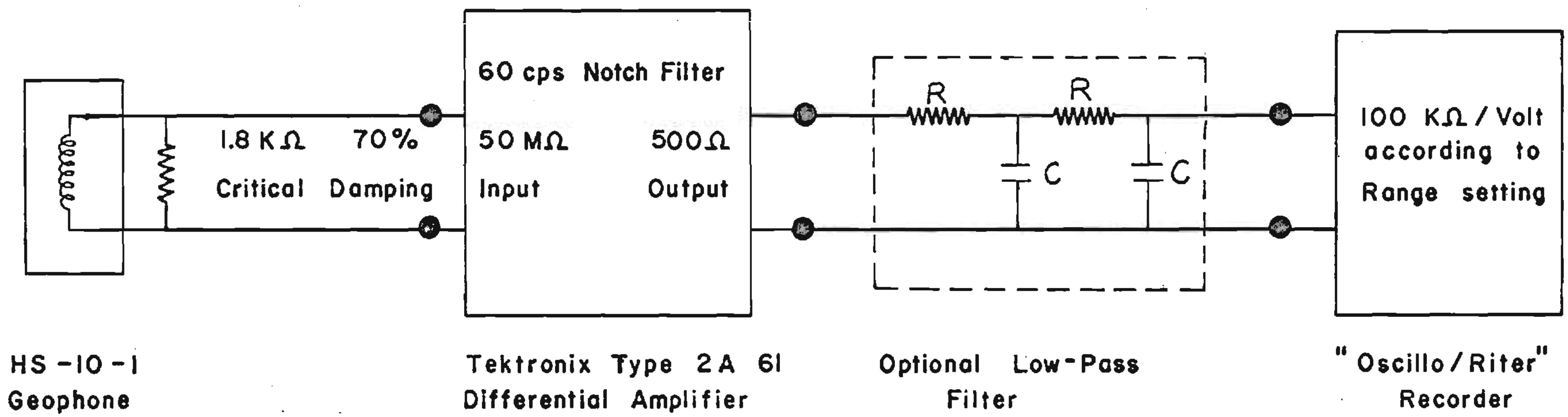

Figure 1. Recording system used to measure seismic noise.

The Texas Instruments two-channel "Oscillo/Riter" recorder was internally calibrated and has flat frequency response up to 80 cps. The velocity and displacement frequency response of the recording system without the filters is shown in Figure 2. A square wave calibration signal of 0.029 volts was applied to the input of the amplifiers before and after each run to check the gain of the system.

SEISMIC NOISE MEASUREMENTS

Regions Examined for Seismic Noise

Three regions were examined to establish existing seismic noise levels and the spectral character of the seismic noise associated with traffic. The Georgia Tech Campus, an urban area, is between heavily traveled I-75/85 and the area west of Hemphill with construction activity. The area near Fernbank Science Center, a suburban region, lacks heavy construction and has only moderate traffic, most of which is along Scott Boulevard and Ponce De Leon Avenue. The West interchange of I-20 and I-285 is a rural environment with seismic noise almost exclusively associated with the interstate highways. In each area the seismic noise was recorded at a number of locations (see Appendix I) varying in distance from the major noise source.

Frequency Character of Seismic Noise

In all local areas where the seismic noise was recorded, the major contribution to both the particle velocity and displacement spectra from traffic noise occurred between 5 and 20 cps. Often frequencies between 8 and 15 cps dominated the record. Sample traces are shown in Figure 3. The existence of a peak in ground noise spectra from 2 to 5 cps has been observed in many areas. The existence of a peak at higher frequencies in this region was

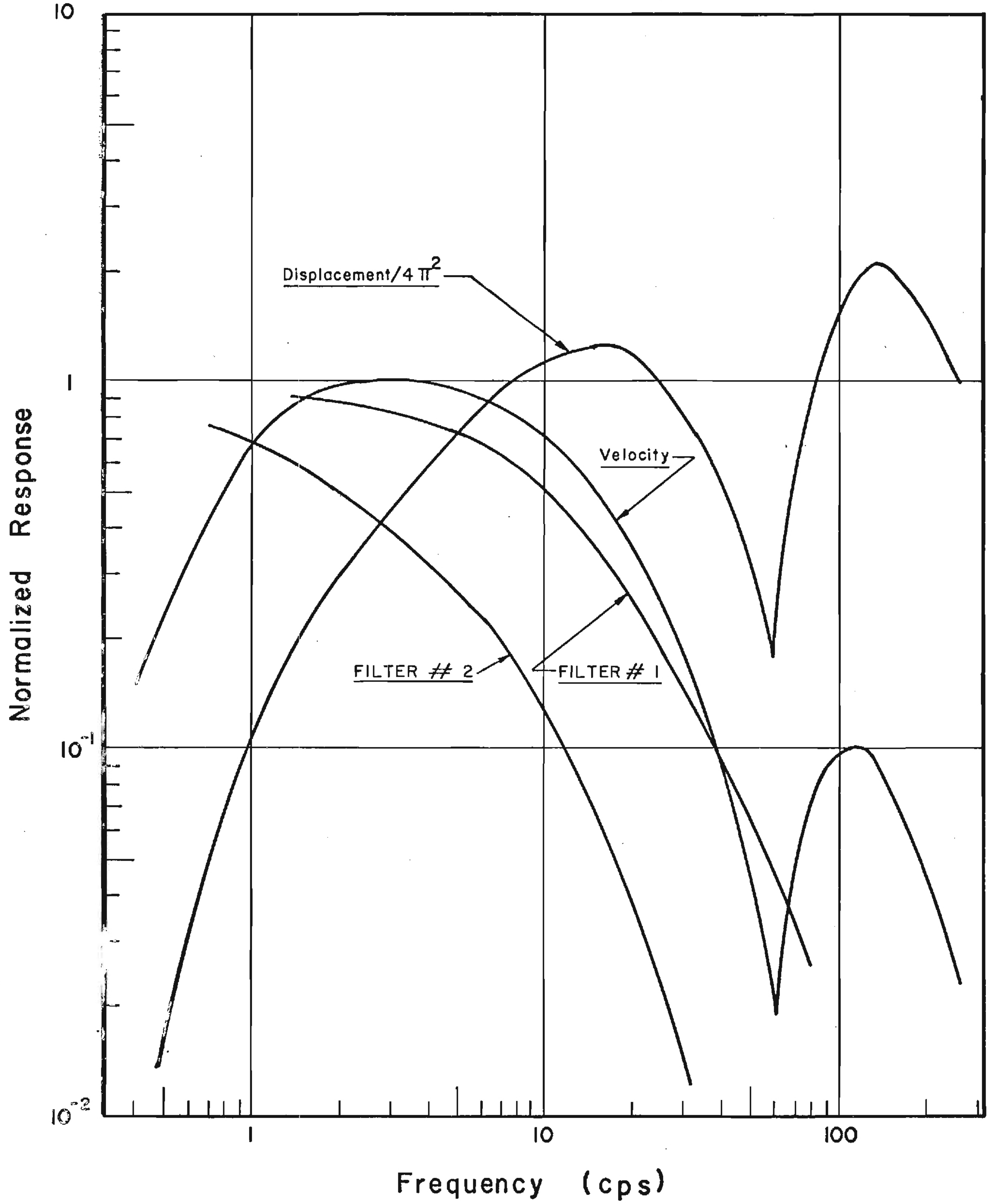

Figure 2. Frequency response of recording system to inputs of velocity and displacement impulse functions and high-frequency attenuation of optional filters.

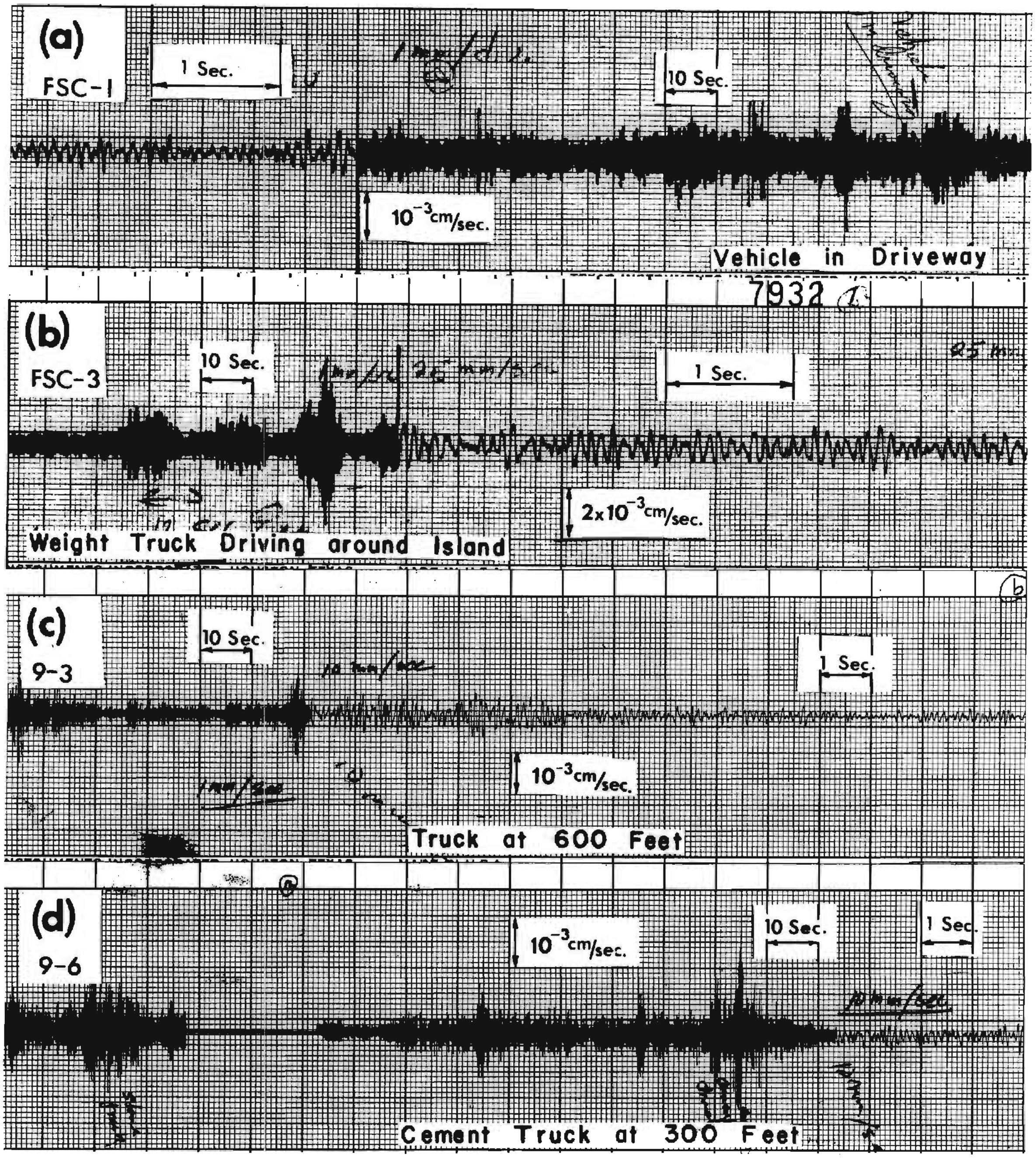

Figure 3. Sample recordings of ground motion: (a) Vertical ground motion 75 feet from pier (b) Ground motion of weight truck (c) Ground motion at 600 feet from highway (d) Ground motion at 300 feet from highway.

expected for two reasons. First, the seismic noise was recorded closer to its source than usual. Because of absorption, high frequency energy attenuates faster with distance than low frequency energy. Hence, at shorter distances, the higher frequencies would be expected to contribute a larger portion of the energy. Second, the high velocity basement rocks are closer to the surface and hence the low velocity surface layer, which transmits most of the seismic surface noise, is thinner. Theoretically the dominant surface wave frequency increases with decreasing thickness and increasing velocity of the layer. Hence, the thinner than average surface layer would be expected to transmit higher than average frequencies.

Regional Variations in the Seismic Noise Level

The minimum level of seismic traffic noise was determined for each station occupied and average values were computed for the three regions considered. These data are listed in Appendix II and the average values are shown on the right hand side of Figure 4. The average minimum noise levels show an expected decrease in amplitude with increased isolation from industrial activity. With the exception of the urban data, the minimum noise level averaged 3×10^{-4} cm/sec. with a variation of about a factor of two. Part of this variation may also be related to the varying physical properties of the surface layer and the geophone plant.

Variation of Seismic Noise With Distance

In the three regions considered the maximum traffic noise and the distance to the source were measured also. (See Appendix II). The maximum seismic noise level was considered to be the maximum seismic noise generated by trucks on the closest highway. The trucks were identified either by sound or by direct visual observation. The distance to the highway was

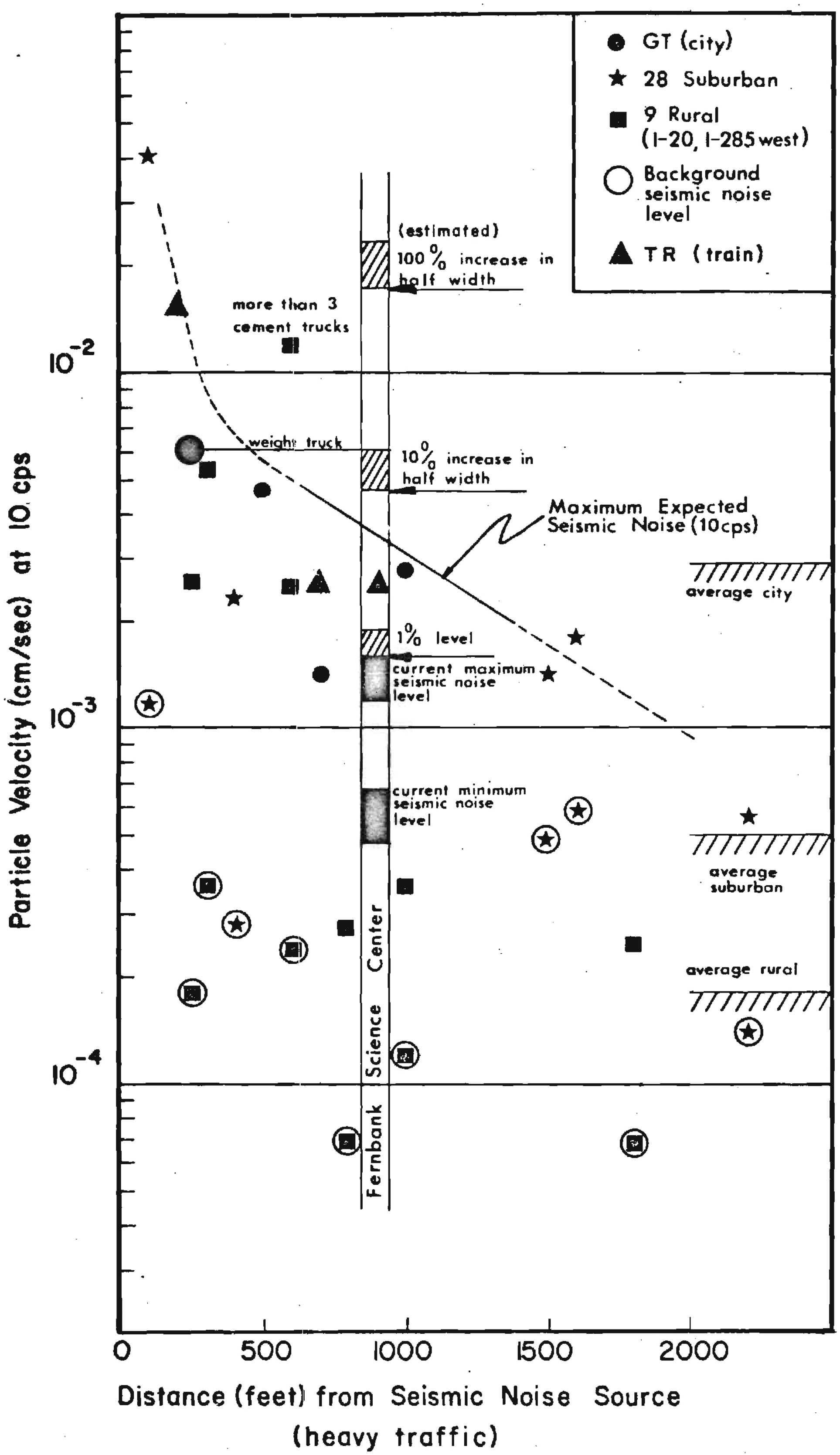

Figure 4. The seismic noise levels measured and their relation to distance.

measured at the site or on a street map. In Figure 4, the maximum noise levels are plotted as a function of distance from the noise source. The maximum values show a decrease with increased distance. The line denoting the maximum expected seismic noise is exceeded significantly by only one point. This point corresponded to an exceptionally large amplitude ground noise of short duration generated by the combined effects of at least three cement trucks. The rural data points at 800 and 1000 feet were exceptionally low. This is probably related to the combined effects of topography and the material properties of the surface layer.

The proposed Stone Mountain Freeway will pass approximately 800 feet from the Fernbank Science Center telescope pier. The distance of 800 feet corresponds to a maximum expected seismic noise level of 4×10^{-3} cm/sec. The average maximum value would be on the order of 2×10^{-3} cm/sec. Furthermore, the data indicate that a value of 9×10^{-3} would be exceeded only in unusual circumstances and then only for time durations of a few seconds.

A measurement of the seismic noise generated by a train was also made (See Appendix II and Figure 4) at distances of 200, 700, and 900 feet from the track. The track is currently located in the approximate location of the proposed Stone Mountain Freeway near the Fernbank Science Center. The 900 foot measurement was taken on the telescope pier. These measurements <u>confirm</u> the amplitude versus distance relation derived from the maximum seismic noise levels. Apparently, the transmission of seismic noise at the Fernbank Science Center does not differ significantly from seismic noise transmission at the other locations where seismic noise was measured.

Current Seismic Noise at Fernbank Science Center

All the stations occupied in the immediate vicinity of or on the telescope pier indicated a seismic noise background level near 6×10^{-4} cm/sec at the peak amplitude frequency of 10 cps. At 10 cps the seismic noise on the pier did not differ significantly from the seismic noise on the ground surface nearby. The value of 6×10^{-4} cm/sec was measured with the telescope drive motor on. The drive motor increased the level of high frequency noise (above 30 cps) considerably. 120 cps component was particularly evident but nevertheless the high frequency noise amplitude did not exceed the amplitudes near 10 cps. The high frequency noise was not evident at ground level. Local traffic in the form of cars on Heaton Street can raise the background seismic level to 1.5×10^{-3} cm/sec (See Figure 4).

Higher levels of seismic noise on the telescope pier were generated in two ways. First, a weight truck (provided through the courtesy of the Georgia State Highway Department) was driven around the island in front of the Science Center. At a distance of 200 to 400 feet the truck, while in motion, generated a seismic noise level on the pier of 7×10^{-3} cm/sec at 10 cps. This noise level compares well with the other truck noise measurements (See Figure 4). Second, the dome covering the telescope was rocked back and forth. This caused motion of the pier equivalent to seismic ground noise of 5.4×10^{-3} cm/sec.

IMAGE DETERIORATION

The usefulness of a telescope depends on its resolution, its ability to distinguish two images close together. A small distant star will appear on a photographic plate as a point. The half-width, width at one half the peak density of exposure, of a point image is one measure of resolution. A number of factors, such as optical imperfection, atmospheric dispersion of light, etc. contribute to the half-width. This project is concerned with the effect of vibration on the image.

To measure image deterioration related to vibration, a series of photographic plates were exposed during periods of low and simulated high level seismic background noise. The data* in Appendix II give the percent decrease in density of exposure at peak density and percent increase in the diameter at the one half (half-width) and one tenth density of exposure levels for the high level seismic noise exposures.

To isolate the effects of vibration on image deterioration (increase in half-width) two assumptions were made.

(1) The half-width which would be caused by seismic noise alone was linearly related to the seismic noise amplitude on the pier.

(2) The seismic noise and the other image deterioration factors combined behave like normally distributed error functions. Hence, the total half-width is the square root of the sum of the squares of the individual half-width. This, in general, is approximately true of seismic ground noise.

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*Paul Knappenberger, Astronomer at Fernbank Science Center, provided the data on image half-width, one tenth width and peak density.

The method of least squares was applied to the half-width and seismic amplitude data to find the best relation between percent increase in half-width and seismic noise level. The results are given in Table II, (See also Figure 4).

TABLE II

Percent increase in half-width	Seismic Noise Level
.1	4.23×10^{-4}
1	1.34×10^{-3}
5	3×10^{-3}
10	4.35×10^{-3}
100	1.64×10^{-2}

The data for Table II were computed from:

$$\% \text{ increase} = \left[(1 + (ku)^2)^{\frac{1}{2}} - 1\right] \times 100$$

Where u = particle velocity at 10 cps (cm/sec) and k = 105.3/.9951, determined by method of least squares.

A comparison of Table II and Figure 4 shows that the maximum expected seismic noise from the proposed Stone Mountain Freeway will cause image deterioration equivalent to a 5 to 8 percent increase in half-width. The average expected seismic noise would increase in half-width on the order of 2 percent. Current noise levels can cause increases in half-widths of 1 percent. The average minimum suburban noise level corresponds to an increase of half-width of .2 percent.

SUMMARY

The current seismic noise on the telescope pier and on the ground surface near the Fernbank Science Center building has an average amplitude of 6×10^{-4} cm/sec at about 10 cps. Frequencies near 10 cps showed the largest amplitudes at the stations occupied. The percent increase in the half-width (See Table II) was 5 at a noise level of 3×10^{-3} and 10 at 4.35×10^{-3}. By comparing these values with seismic noise levels measured at varying distances from major highways, Figure 4, the maximum expected traffic seismic noise from the proposed Stone Mountain Freeway would increase the half-width 5 to 8 percent. The average traffic seismic noise measured would imply an increase in the half-width of about 2 percent.

LIMITATIONS OF THE DATA

The seismic noise level versus distance function (Figure 4) depends on both the topography and geologic surface structure. The proposed Stone Mountain Freeway, when constructed, will alter the topography and hence alter the transmission of seismic wave noise. Further studies would have to be conducted to determine the topographic modification that would minimize the transmission of seismic surface waves.

The coupling of traffic road noise to the ground by the road bed may also be depended on the road bed material. Types of road bed material could be examined to determine the best for decoupling road noise from the ground.

The dominant frequencies (8-15 cps) are characteristics of the closeness to the source and high velocity material overlain by a thin lower velocity surface layer. A significant thickness of alluvial material or low velocity sedimentary rock, such as is found in South Georgia, would change, considerably, the coupling of traffic road noise to the ground, the amplitude distance function and the dominant frequencies of the energy transmitted. For these reasons the conclusions of this report should not be applied to other localities without additional measurements.

APPENDIX I

RECORDING STATION LOCATIONS AND DESCRIPTIONS

GT-1 Southwest corner of 10th and Fowler Street. Seismometers placed on grass next to road and on grass less than three feet from net of tennis court 700 feet west of I-75/85.

GT-2 Southeast corner of Atlantic and 5th Street. Seismometers placed 25 and 100 feet south of 5th Street at eastern edge of parking lot. 2000 feet west of I-75/85, 500 feet to Hemphill and construction area.

GT-3 Southwest corner of 5th and Fowler Street. South edge of parking lot approximately 250 feet west of Fowler. 1000 feet west of I-75/85.

FSC-1 Fernbank Science Center yard approximately 75 feet east of telescope pier. Time: 6:00 PM.

FSC-2 Fernbank Science Center - Seismometer placed on pier. Time 6:00 PM.

FSC-3 Same as FSC-1 at 11:00 PM. High level seismic noise simulated by driving a weight truck near the pier.

FSC-4 Same as FSC-2 at 11:00 PM. High level seismic noise simulated by driving a weight truck near the pier.

<u>March 28, 1969 Between 9:00 and 11:30 AM</u>

28-1 Grass island in front of Fernbank Science Center 1600 feet from Ponce De Leon Avenue.

28-2 Coventry Road intersections with railroad track. Seismometer placed 50 feet south of Coventry next to track 1500 feet from Scott Boulevard.

28-3 Northeast corner of Scott Boulevard and Nelson Ferry Road 100 feet from Scott Boulevard in gravel parking lot.

28-4 Northwest corner of Coventry and Coventry Place. Seismometer placed in grass lot about 25 feet from Coventry Road, 2200 feet from Ponce De Leon Avenue.

28-5 East end of Deepdene Park. Seismometer placed 50 feet from North Ponce De Leon Avenue, 400 feet from Ponce De Leon.

April 9, 1969 Between 9:30 and 11:30 AM

9-1 Oakcliff Road 1000 feet west of I-285 seismometer placed at end of road. 2000 feet south of I-20.

9-2 Oakcliff Road at Hemphill School Road seismometer placed in school yard next to tennis courts; 1800 feet west I-285, 2000 feet south I-20.

9-3 Oakcliff Road at corner of Harwell Road 600 feet west I-285.

9-4 Stratford Drive at Mail Box 156 near end of road, 250 feet south of I-20.

9-5 Corner of Stratford Drive and Oakcliff Road. Seismometer placed 100 feet from Stratford Drive, 800 feet south I-20, 1200 feet east of I-285.

9-6 Oakcliff Road 300 feet east of I-285.

April 11, 1969 Between 10:50 and 11:40 AM

PV Vertical seismometer placed on pier.

PH Horizontal seismometer placed on pier.

SV Vertical seismometer placed on sidewalk next to observatory.

(1 = background, 2 = drive motor noise, 3 = rotation of dome)

APPENDIX I (Continued)

May 7, 1969 (Measurement of train noise)

TR-1 Horizontal seismometer on pier.

TR-2 Vertical seismometer 200 feet from pier toward train track (west).

TR-3 Vertical seismometer 700 feet from pier toward train track (200 feet from track).

APPENDIX II

MEASURED PARTICLE VELOCITY AT 10 CPS

	Distance Feet	Particle Velocity (cm/sec) Minimum	Maximum	Minimum Average
Urban				
GT-1	700	No significant low-level periods observed	1.4×10^{-3}	
GT-2	500	"	4.6×10^{-3}	2.9×10^{-3}
GT-3	1000	"	2.8×10^{-3}	
Suburban				
28-1	1600	5.8×10^{-4}	1.74×10^{-3}	
28-2	1500	4.8×10^{-4}	1.4×10^{-3}	5.3×10^{-4}
28-3	100	1.16×10^{-3}	4×10^{-2}	
28-4	2200	1.4×10^{-4}	5.6×10^{-4}	
28-5	400	2.8×10^{-4}	2.3×10^{-3}	
Rural				
9-1	1000	1.2×10^{-4}	3.6×10^{-4}	
9-2	1800	6.7×10^{-5}	2.5×10^{-4}	
9-3	600	2.4×10^{-4}	1.2×10^{-2}*	1.7×10^{-4}
9-4	250	1.8×10^{-4}	2.7×10^{-3}	
9-5	800	7×10^{-5}	2.8×10^{-4}	
9-6	300	3.7×10^{-4}	5.4×10^{-3}	

*Note: Three unusually large trucks. Average maximum truck noise is 2.5×10^{-3}.

APPENDIX II (Continued)

	Distance Feet	Particle Velocity (cm/sec)
Train Noise		
TR-1	200	1.5×10^{-2}
TR-2	700	2.7×10^{-3}
TR-3	900	2.7×10^{-3}

	Particle Velocity (cm/sec)
PV-1	3.8×10^{-4}
PV-2	5.6×10^{-4}
PV-3_a	5.4×10^{-3} High level
PV-3_b	1.4×10^{-3} Low level
SV-1	3.8×10^{-4}
SV-2	3.8×10^{-4}
SV-3	1.9×10^{-3}

	Verticle Seismometer	Horizontal Seismometer
FSC-1	1.3×10^{-4}	5.6×10^{-4} (ground) minimum
FSC-2	4.9×10^{-4}	5.8×10^{-4} (pier) noise levels

Deterioration data (provided by Dr. Paul Knappenberger)

Density Tracing	Peak	Half width	1/10 width	FSC-3 (ground)	FSC-4 (pier)
NT	148.5	26.25	57.0	6×10^{-4}	3×10^{-4}
QR	143.75	27.75	58.75	*4×10^{-3}	*7×10^{-3}
	3.2%	5.6%	3.0%		

* High amplitude occurred only during one half the exposure time.

APPENDIX II (Continued)

Density Tracing	Peak	Half width	1/10 width		
FG	78.75	8.50	15.5	† PV-2	5.6×10^{-4}
HI	77.30	9.65	17.0	PV-3	5.4×10^{-3}
	1.8%	13.5%	9.7%		
JK	99.0	12.35	19.0	PV-2	5.6×10^{-4}
LM	94.5	14.35	22.0	PV-3	5.4×10^{-3}
	4.5%	16.0%	15.8%		

† PV data not taken at same time as exposures.